Photovoltaic Power plants: A Possible Solution for Growing Energy Needs of Remote Bangladesh.

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Abstract:

The environment in the east, south and north-eastern parts of Bangladesh has an abundance of solar radiation along with high levels of UV radiation and humidity. In addition, there are also remote areas where the establishment of conventional power plants is not feasible, nor is grid extension. In these areas, a mixture of small to mid-scale photovoltaic plants can be a suitable alternative if the cells can be protected from the unique environmental conditions. The solution to this specific problem can be addressed in three ways, by improving efficiency of the cells, improving light absorption stability and by extending the service life of the cells. In this paper, a look into three different works by other researchers is looked at to find a possible solution to this problem in this specific context of Bangladesh. Improvement of efficiency can be done by means of nanofluid cooled systems; for improvement of light stability cells manufactured using coupled plasma deposition method may be especially helpful in this context. The durability and service life of cells can be extended by using various polymeric encapsulates.

Keywords: photovoltaic cells; environmental effects; durability enhancement; photovoltaic plants; solar energy.

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1.0 Introduction

The impact of conventional fossil fuels on planet earth has already caused significant ecological changes and alterations to the environment. Its effect can be felt through many aspects of current life, extreme weather patterns in countries like Bangladesh, loss of land due to rising of sea level, and reduction of marine and wildlife. Adding to this the demand for energy is only ever increasing as more and more countries start to advance and populations tend to grow. And so, now more than ever, the effective use of alternative energy sources is of the highest priorities of government and scientists across the globe. Wind, geo-thermal, tidal, hydro, solar, fuel cells and biomass are some of the main forms of energy which have been looked at throughout the last decades so far[1]–[4]. Among all these types, solar is the most abundant and ubiquitous. The sun is an almost inexhaustible source of free energy. Hypothetically the amount of solar radiation incident on planet earth annually is more than enough for the energy needs of the entire planet earth, if proper energy harvesting technology can be developed [5]. Annually four million exajoules of energy reaches planet earth out of which almost fifty thousand exajoules ($5x10^4$ EJ) is harvestable [6]. Solar energy can be harvested in two major ways, one is the establishment of solar thermal plants, which require considerable flat land and the other is the use of photovoltaic plants which have no such requirements [7]. The major limitation of PV plants has been that the efficiency and durability is lower compared to solar thermal plants. However, advancement in fabrication techniques and material synthesis has meant an improvement in the efficiency of PV cells. In this context PV plants are gradually becoming more viable as they are stand alone, off grid and can be coupled with other renewable sources [8]–[10]. This becomes especially evident in communities and populations far removed from the conventional power grid network. Many such projects have been investigated throughout the world [11]–[13]. Especially the regions near the equator are the best candidates for using such PV plants for their remote regions as they have abundance of solar radiation. Even if they can't replace conventional fossil fuel generators and plants, hybrid systems of such photovoltaic plants and conventional fossil fuel facilities can certainly reduce the dependance on the later as suggested by Shezan et al [14].

Many researchers have focused on improving of PV cells by different means [15]–[17]. With such wide spared interest and research into PV plants and cells, it is only natural that the methods and results be investigated in the context of remote areas of Bangladesh were both the geography and the adverse climate conditions prevent the adoption of PV plants. Figure 1 shows the availability of solar radiation and potential for plants in Bangladesh.

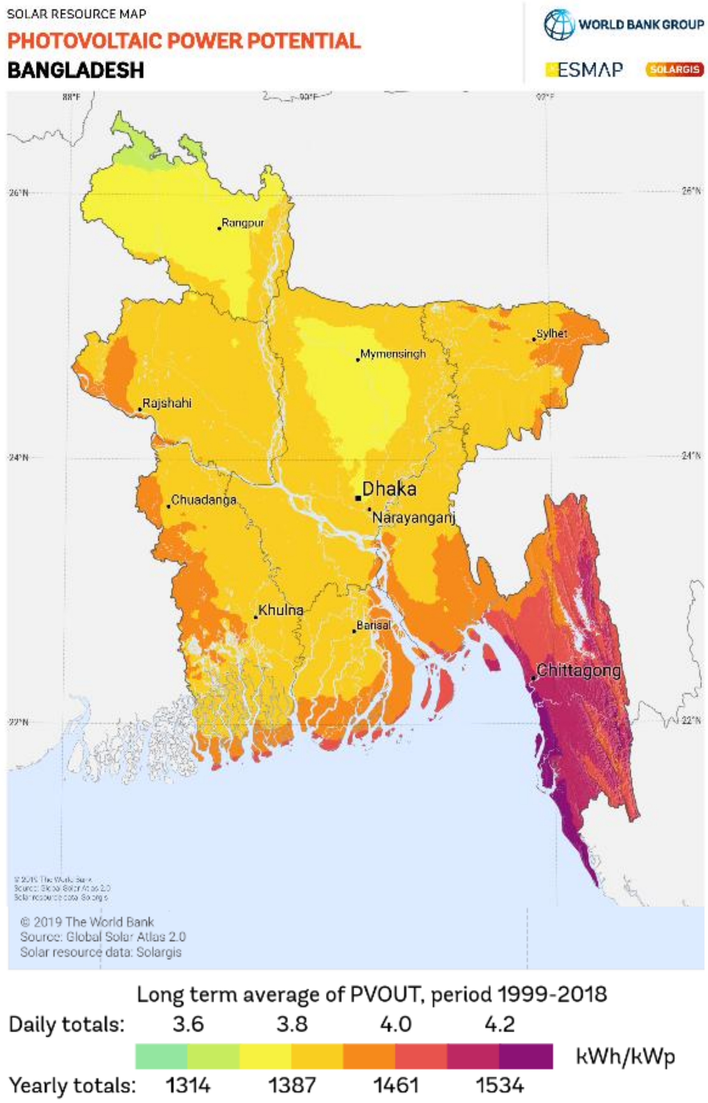

Figure 1: Availability of solar radiation and potential for plants in Bangladesh [18].

2.0 Advantages of Photo Voltaic Plants vs Other Types

Though Bangladesh has abundance in renewable energy sources, the choice of which type of plant to use also depends on other factors. For example, availability year-round, cost of the plant, its footprint on the environment, ease of maintenance, suitability for type of application (year-round availability, plant expense, environmental footprint, ease of maintenance, suitability of the application) etc. Solar PV is dominated on market size and technological simplicity over CSP. On the other hand, CSP plants can store thermal energy for up to 16 hours. CSP's production profile can match the demand profile [19]. Figure 2 exhibits the comparisons between solar PV and CSP system. In this section other forms of powerplants are examined in the context of application to remote places located in south, east and southeastern parts of Bangladesh for small and mid-sized settlements.

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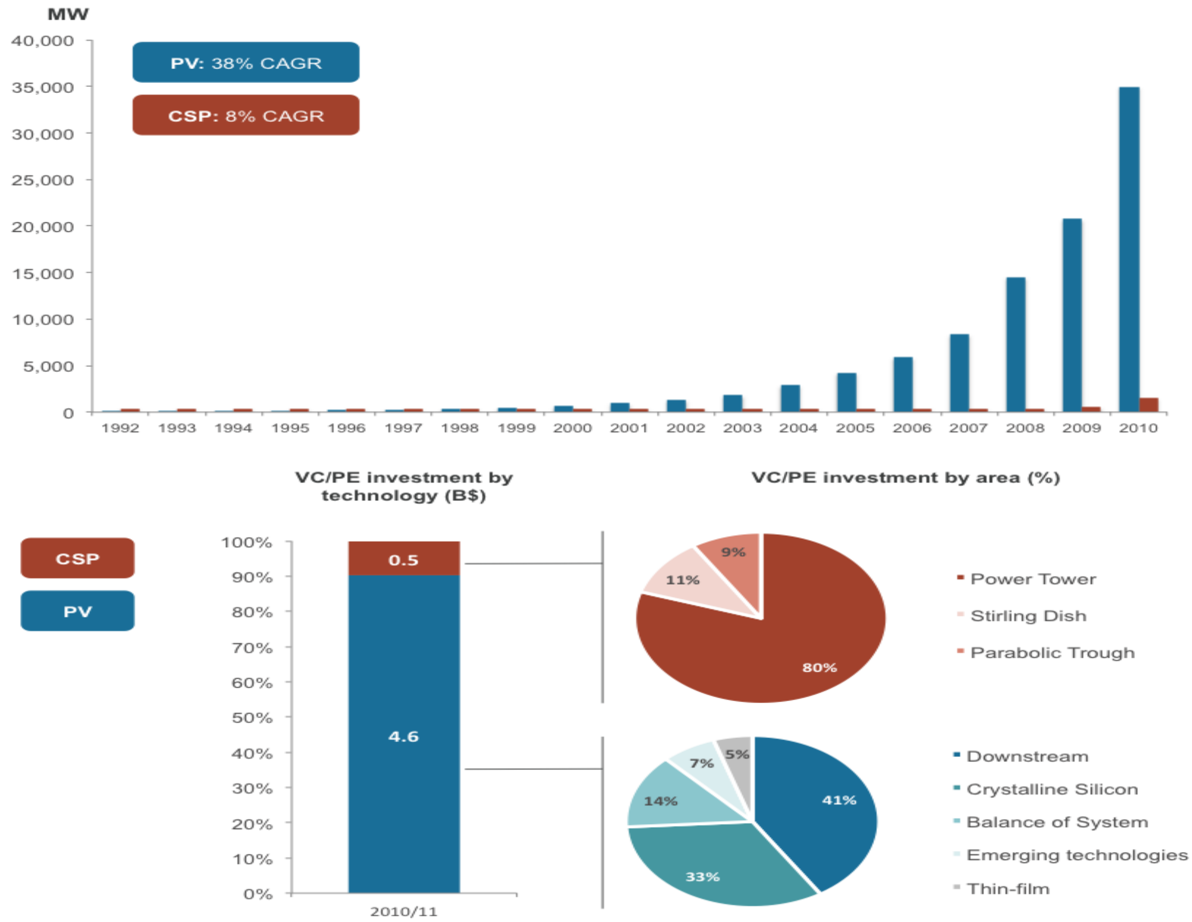

Figure 2: the comparisons between solar PV and CSP system [19].

3.0 Limitations of Wind Power for Remote Bangladesh

Wind power and wind turbines have come a long way and are probably the most widespread of all the sustainable energy sources out there. In countries like Germany, USA, UK and China, wind farms both offshore and onshore are used extensively as a compliment to more conventional means of power generation. The capacity factor of wind plants ranges in between 15–50% [20]. Indeed, areas with high average wind speeds year-round are better off using wind power. However, establishment of wind farms is not without its drawbacks as well. Firstly, a viable find farm even for small to mid-sized communities requires considerable area as well as flat lands as well. Ironically these requirements can often mean that establishment of eco-friendly wind firms requires clearing of forest giving rise to deforestation concerns [21]. This is one of the major reasons why wind farms are not suitable for large parts of Bangladesh, especially the remote areas of the south, east and south-east region. The second major requirement for wind farms is year-round availability of winds with sufficient speed. Though many parts of Bangladesh receive fair amount of wind, especially in the coastal regions in the south, many remote regions surrounded by dense foliage in the east, south-east and Sundarbans region do not [22]. Even in places where wind

speed is relatively high, the wind patterns are erratic and yearlong sustainable speeds are not found [23]. So, in this regard, wind power and wind firms are not a viable solution for remote inland parts of Bangladesh.

4.0 Limitations of Conventional (Coal/Gas) Fossil Fuel pants for Remote Bangladesh

As we all know, conventional power plants powered by coal or gas still remain unbeaten in terms of cost and efficiency. However, establishing such power plants exerts a great toll on the environment and natural resources. Coal plants especially can have a sever damaging effect on environment [24]. Gas plants require using natural gas, which is a precious commodity here in Bangladesh, as it is required for many industries, vehicles and households. Moreover, establishment of newer powerplants require additional structures in the form of lines, substations and such. These additional structures once again require land and exert even more pressure on the foliage around. Bangladesh already faces a major challenge in stopping deforestation as most of the forest areas are already under pressure from expanding population and infrastructure [25]. Finally, for many remote places the establishment of conventional powerplants or grid extension is not feasible, especially in east and south east region were dense greenery and uneven lands prevails.

5.0 Some new developments and their possible applications in the context of Bangladesh

Durability and efficiency of photovoltaic plants is the major issue in terms of use in environments like that of Bangladesh. In this section various recent developments for improving durability and efficiency of photovoltaic cells and plants and how these developments and techniques can be applied in the context of Bangladesh are looked into.

6.0 Improving Efficiency

PV cells absorb about eighty (80) percent of the solar energy incident on their surface but, their conversion percentage is relatively poor, just about 12 percent to 18 percent at best reaching 25%. Remaining solar radiation is converted to heat that increases the PV cell temperature to 40 ° C above ambient temperature [26], [27]. In this regard high operating temperatures is one of the major impediments for power generation through photovoltaic cells. One possible way of improving the efficiency of PV systems is by regulating the temperature of the panels through active and passive means. There are many different types of PMCs used. Substances such air, water, nanofluids etc. are used in actively cooled systems. Were as substances like paraffin wax, eutectics, organic materials, cotton wick and other phase change materials are used in passively cooled systems [28].

7.0 Nano-Fluid Cooled System

One method of achieving higher efficiencies is by utilizing nano-fluid cooled photovoltaic systems. There have been numerous investigations into the performance of nano-cooled photovoltaic cells. Though nano-particles can have relatively costly preparation procedure, the benefits such a system can provide in terms of improving solder cell performance can outweigh the costs, especially for a mid-sized plants large enough to power small isolated communities in the south and south eastern parts of Bangladesh where solar

radiation is abundant year long and the establishment of conventional powerplants is next to impossible due to the impact on local environment and wildlife. Sardarabadi et al. investigated various metal oxide/water combinations in hopes of improving efficiency [29]. For their experiments, they used simple deionized water, TiO_2 / water, Al_2O_3/ water and ZnO/ water systems for cooling. In all the cases the efficiency of the solar collectors improved. The surface temperatures for their PVT systems are given below.

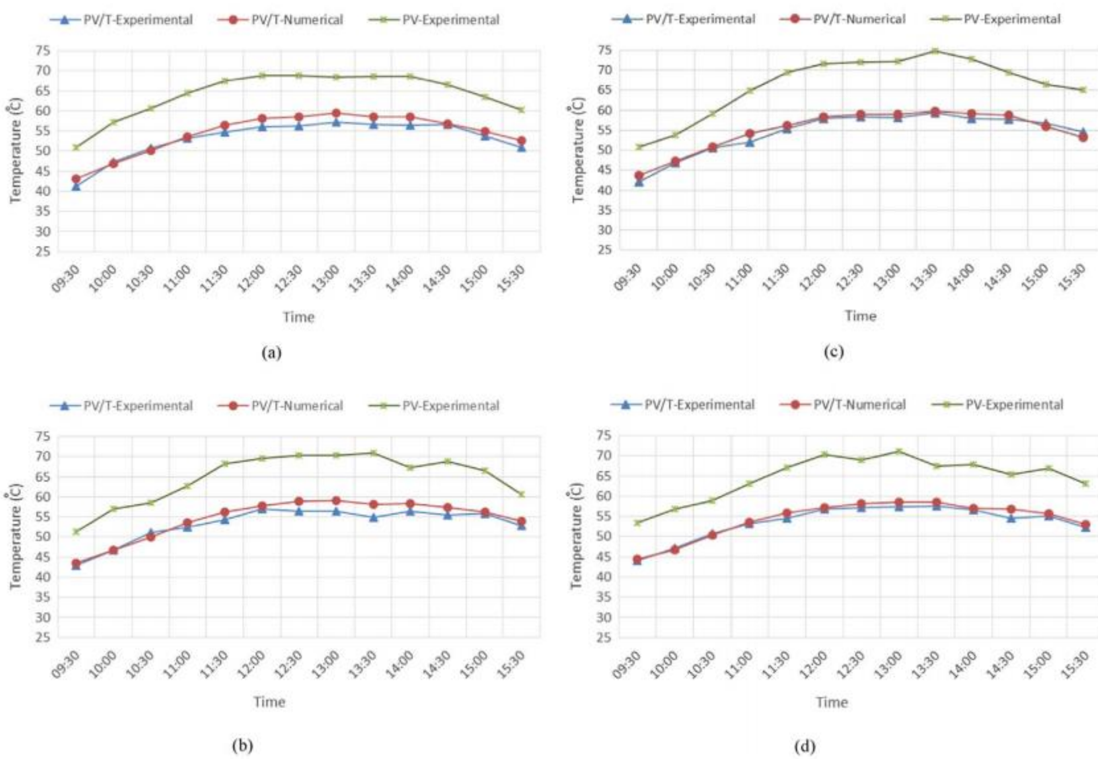

Figure 3: Measured and computed surface temperatures of the PVT system in comparison to the measured PV system values: (a) deionized water (b) TiO_2/ water nanofluid (c) ZnO/water nanofluid and (d) Al_2O_3/water nanofluid [25].

Figure 3 shows a reduced surface temperature for the photovoltaic cells, especially those of ZnO and TiO_2 systems. This is especially significant in the case of use in Bangladesh, as the temperatures regularly rise beyond 40°C. Lowered surface temperature of the PV cells means better performance of the cells and more longevity of the cells. Both of which are required for operation in remote and hot climates of Bangladesh. Naturally, the reduced operating temperatures for the PV systems means a marked improvement in efficiency as well. The results of their study on the efficiency aspect are given in figure 4. They found that the improvement in efficiency for the water, TiO2, ZnO and Al2O3 systems were 5.48%, 6.54%, 6.46% and 6.36%, respectively. The mass fraction of the particles used was 0.2% for all the systems.

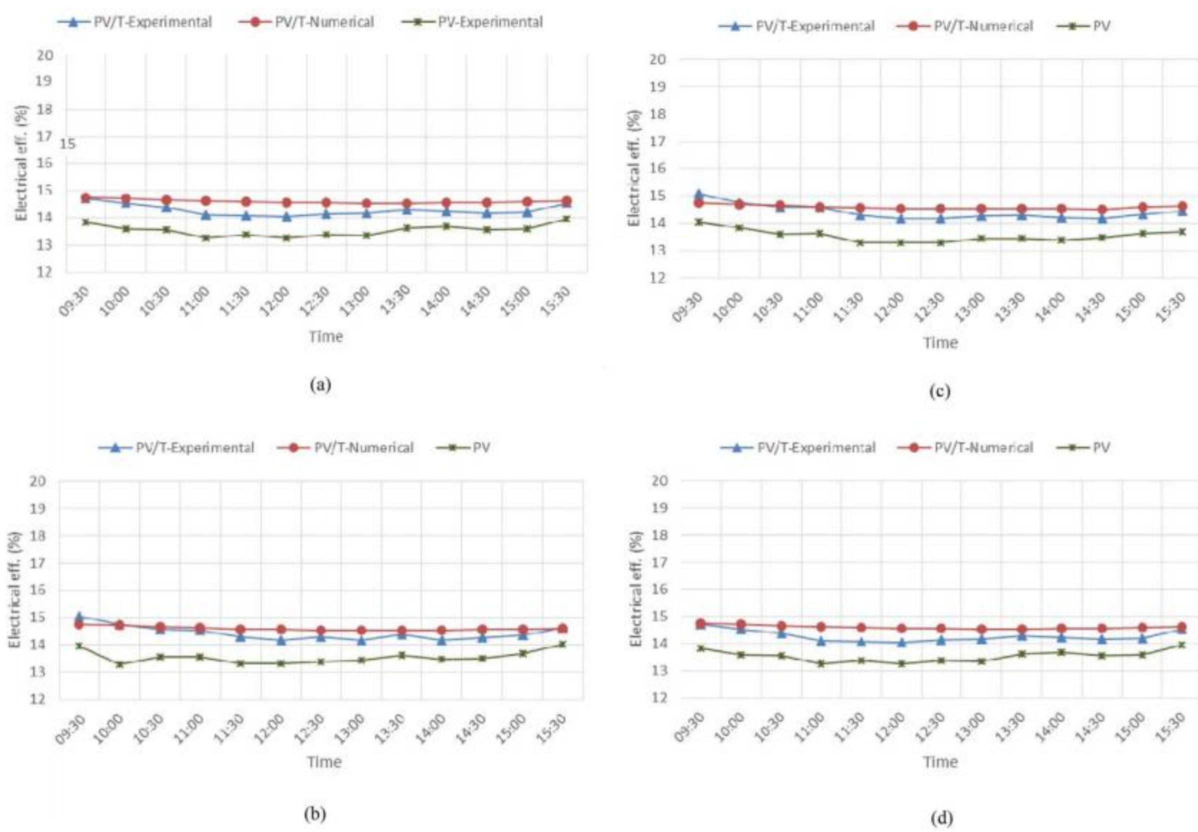

Figure 4: Experimental and numerical electrical efficiency of the different PV/T systems as compared with purely PV system: (a) Deionized water, (b) TiO_2/ water nanofluid, (c) ZnO/water nanofluid and (d) Al_2O_3/water nanofluid [29].

Which is also a significant point to consider in the context of remote Bangladesh and small community use. Since the mass fraction of the required particles is so less, it implies that the supposed increased cost for using nanofluids is mitigated and the efficiency gains clearly justify the use of such fluids for mid-sized plants capable of powering small communities.

8.0 Improved Light Absorption Stability:

Another vital aspect to consider when dealing with PV plants is the radiation-socking stability of PV cells. There have been various inquiries into reducing the degradation of PV cell materials. However, most of these investigations involved costly and expensive manufacturing techniques. Huang at el. investigated a technique to lower these expanses and at the same time improve the stability and degradation characteristics of solar cells. They investigated cells manufactured using the inductively coupled plasma (ICP) deposition method. ICP systems have low defect density ($3x10^{-15}$ cm^{-3}) and consequently also have increased conversion efficiency [30]. Their results are discussed below, which show the effectiveness of their method and make a positive case for use of such kind of solar cells in Bangladesh, especially in regions were more IR radiation levels are present (Sylhet and other eastern regions).

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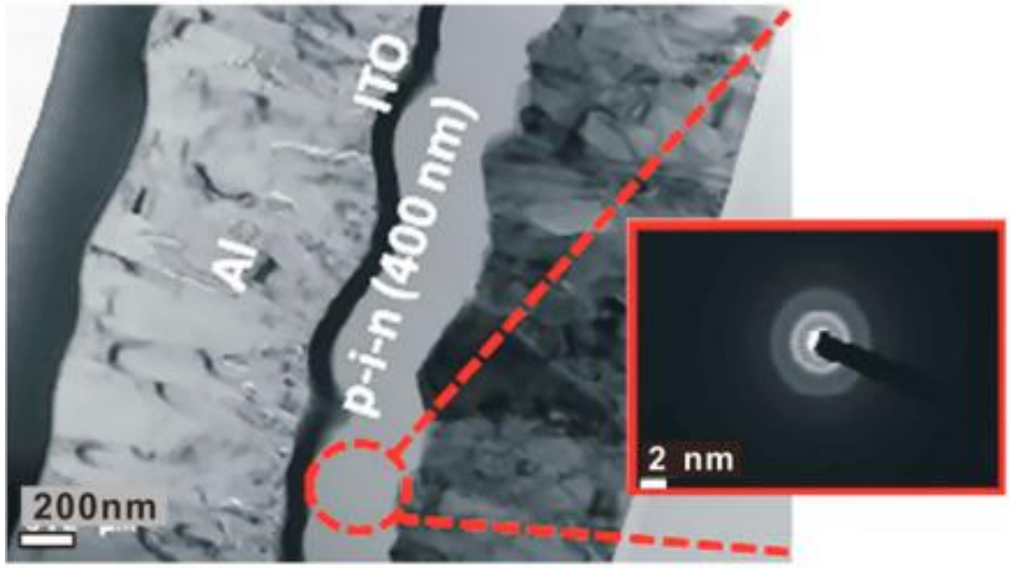

Figure 5: Cross section of a-Si pin PV cell on Asahi-U substrate as reported by Huang et al [30].

Figure 5 shows the cross section of a-Si pin PV cell on Asahi-U substrate. The solar cells yield significantly better results than conventional silicon-based PV cells, which is supported by the microscopic diagram. They compared their data with a VHF-PECVD system operating at 40 MHz with power density of 83 mW/cm^2. Their own solar cells were subjected to operating conditions of 135 mW/cm^2. Figure 6 represents the current density vs voltage plots of a-Si pin solar cells at 140 ℃ and infrared absorption spectra. It indicated a favorable outcome for their ICP system, 9.6 percent PV conversion efficiency with a short-circuit current density of 15.7 mA / cm^2, V_{oc} open-circuit voltage of up to 0.91 V. A high fill factor of 67% results in a low dark saturation current density of 1.3x10^{-9} A/cm^2. Conversely, with V_{oc} (0.92V) and FF (67.7 percent), the JV characteristics of VHF-PECVD solar cells had a lower conversion efficiency of about 8.8 percent. The density of the short-circuit current was much lower (14.2 mA/cm^2) than that of the ICP system.

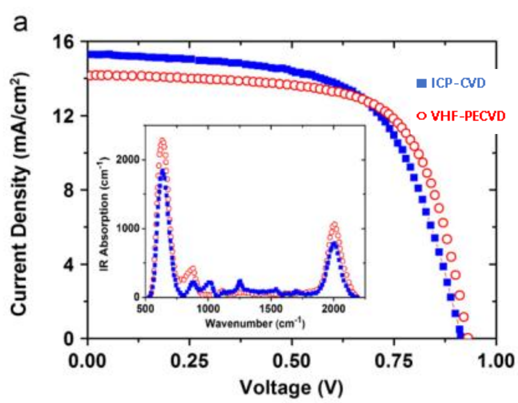

Figure 6: Current density vs voltage plots of a-Si pin solar cells at 140 ℃ and infrared absorption spectra [30].

They reported that the PV efficiency of the ICP solar cell decreased by twelve percent from 9.6 percent to 8.5 percent after exposure of 10^4 seconds at 60 °C with six-Sun (Figure 7a). PV efficiency of the VHF-PECVD cell decreased even further, by 19 percent after the same period of exposure. The light soaking-induced changes in J-V curves were mainly seen in a decrease in the fill factor and short-circuit current, indicating that light soaking generates new carrier losses [30].

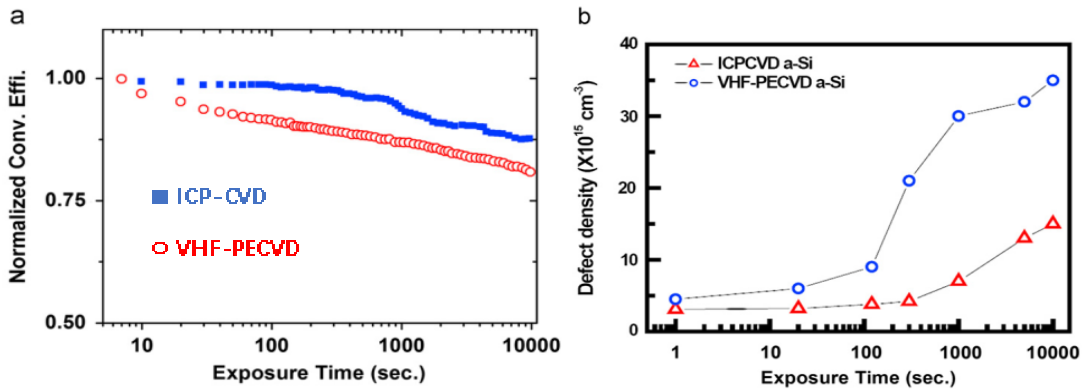

Figure 7: Variation of conversion Efficiency with irradiance exposure time. (b) Variation of defect densities with exposure time as presented by Huang et al [30].

The defects in a thin-film solar cell can act as carriers' recombination centers that shorten the lifetime of the carrier and create dipoles that further screen the electric field in the solar cell absorber layer. They measured the defect density of a-Si: H films as a function of exposure time with the DLCP method to explain the associated light soaking-induced degradation process. For the measurements, 400-nm thick intrinsic a-Si:H films were deposited on P^+ c-Si substrate at 140°C. They found, (figure 7(b)) that the defect density of the ICP a-Si: H film was 3×10^{15}cm^{-3}, while the defect density of the VHF-PECVD a-Si: H layer was significantly higher at 6×10^{15} cm^{-3}. After 10^4 seconds of six-Sun irradiation, the defect density of the ICP a-Si film increased to 1.5×10^{16} cm^{-3} compared to 3.5×10^{16} cm^{-3} for the VHF-PECVD a-Si film under similar conditions [30].

From their instigations, it is clear that utilizing Inductively Coupled Plasma (ICP) deposition manufacturing or by employing PV cells manufactured by the ICP method, power generation and efficiency of photovoltaic plants can be greatly improved. Such cells can especially be useful in the remote regions of eastern and south-eastern parts of Bangladesh, where solar cells are subjected to high amounts of IR radiation.

9.0 Durability and Service Life Enhancements

Improving the operational durability of PV plants is also important for cost effective and viable application of PV plants. During outdoor operation, PV systems are subjected to different external conditions (weather, soil, humidity etc.) that can potentially affect their optical, mechanical, thermal, and chemical stability and eventually lead to a decrease in performance. This loss of device and/or module efficiency is a sever limitation that cannot be

overcome by simply improving intrinsic stability and quality of the single material constituting the photoactive cells. In recent years there have been many investigations into the enhancement of durability of PV cells in operation. One of the most promising ways this enhancement of durability is achieved is by using polymeric materials as protective covering or coating for the PV cells. Especially in the context of remote Bangladesh this is especially important because of the high levels of humidity, UV radiation present in the environment. These protective coatings are relatively cost effective as well in comparison to using PV cells made o exotic materials and processes for high durability applications. As before, some of the works by done in this regard is highlighted in the following section with specific reference to application in in this region.

10.0 Polymeric Encapsulants

Polymeric encapsulants are basically are basically polymer materials layered on top of solar cells. Depending on the type of material used as these encapsulants, the durability of normal PV cells can be greatly enhanced, extending the service life of the PV cells. Moreover, if applied accordingly, these same protective layers can act as a sort of radiation concentrates for PV panels. A thorough investigation on different types of encapsulants was done by Miller et al [31]. They conducted 36-month long investigation of different polymer encapsulants such as EVA, PVB, PO, TPU, PDMS, PDPDMS and PPMS. Their results showed that all the coatings showed (table 1) resistance to degradation and aging under outdoor conditions. As a demonstration of this, their results concerning the transmittance of the materials is given below [31]. They found that all the materials had remarkably stable transmittance. This points towards to the conclusion that no matter the type of polymer used in coating or encapsulating the PV cell, a significant increase in service life can be expected. This opens the door for use of inexpensive commercial polymers as encapsulates and coating material as well, which is significantly important in the context of PV plants in remote regions of Bangladesh were environment conditions are harsh and frequent maintenance may not be possible.

Table 1: Change in photon transmittance and specimen mass after 36 months [31].

Specimen type	Δτ (300≤λ≤650 nm), (%)	Δτ (650≤λ≤890 nm), (%)	Δτ (890≤λ≤1800 nm), (%)	ΔYI	$\Delta\lambda_{cUV}$	Δm, (%)
EVA	-0.77 ± 2.98	0.06 ± 0.43	0.34 ± 0.16	0.01 ± 0.66	3 ± 17	-0.03 ± 0.02
Lonomer	-0.80	-0.26	0.13	-0.02	0	-0.55
Ployolefin	0.10	0.14 ± 2.45	0.38 ± 1.36	1.11	17	-0.03 ± 0.01
PVB	-0.06	0.14	0.22	-0.07	1	-0.16
TPU	-0.10	0.01	0.57	-0.09	1	-0.02
PDMS	-0.16 ± 0.41	-0.07 ± 0.29	-0.01 ± 0.22	0.37 ± 0.51	0 ± 14	-0.03 ± 0.12
Statistical Outliers	EVA3, EVA4, PDMS12,	EVA3, EVA4, PDMS6,	EVA3, EVA4, PDMS12,	PDMS 7, PDMS 11,	EVA1, EVA2	None

	PDPDMS-CH=$CH_2$1, PDPDMS–CH=CH_2 2	PDMS12, PDPDMS–CH=$CH_2$2, PPMS	PPMS, PDPDMS–CH=CH_2 2	PDMS 12, PDPDMS–CH=CH_2 1		
Exemptions	Polyolefin 1	None	None	Polyolefin 1	Polyolefin 1	EVA1, PDMS13, PDMS14

Idígoras at el. on the other hand explored the application of ultra-thin plasma polymer coating for Perovskite solar cells [32]. Though the study involved Perovskite cells, the same encapsulating techniques may be applied to conventional PV cells as well. Their investigation can be especially important in the case of remote Bangladesh because it specifically focuses on high humidity environment. Figure 8 exhibits the current density vs voltage curves for unencapsulated and encapsulated devices for different times. With respect to devices without encapsulation, the degradation in the photovoltaic output of the encapsulated devices was significantly delayed when continuously ventilated with very humid air (RH > 85 percent). In reference to their work, the efficacy of their encapsulating material can clearly be seen from their plots of current density vs cell potential, as given below.

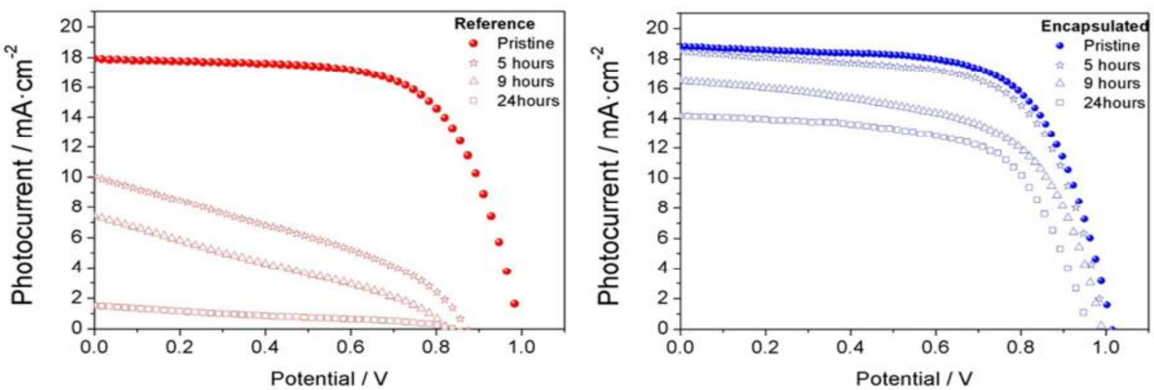

Figure 8: Current density vs voltage curves for unencapsulated and encapsulated devices for different times [32].

It can be easily seen that with immersion in the polymer solution the durability of the PV cell increases dramatically. So, a similar method applied to solar PV cells using some cost-effective polymer encapsulants which provide a balance between protection and initial fabrication cost can significantly increase viability of PV plants in the humid eastern part of Bangladesh.

11.0 Conclusion

A variety of methods and advances have been highlighted in the previous sections, along with the advantages and reasons for prioritizing PV plants over conventional grid extension and other forms of renewable energy sources. At this point, it can be safely said that with such advances in PV cell technology, the establishment of small to mid-scale PV plants in the remote, wildlife and vegetation-rich areas

of Bangladesh is certainly a viable and environmentally friendly option, at the very least hybrid plants like combined Diesel-solar plants should be considered. The implementation of these technologies should be done as soon as possible as this will also help to reduce dependency on other nations on solar PV technology in the future as well.

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